Lattice Gauge Theory at Fermilab

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Additional material at:
http://lqcd.fnal.gov.

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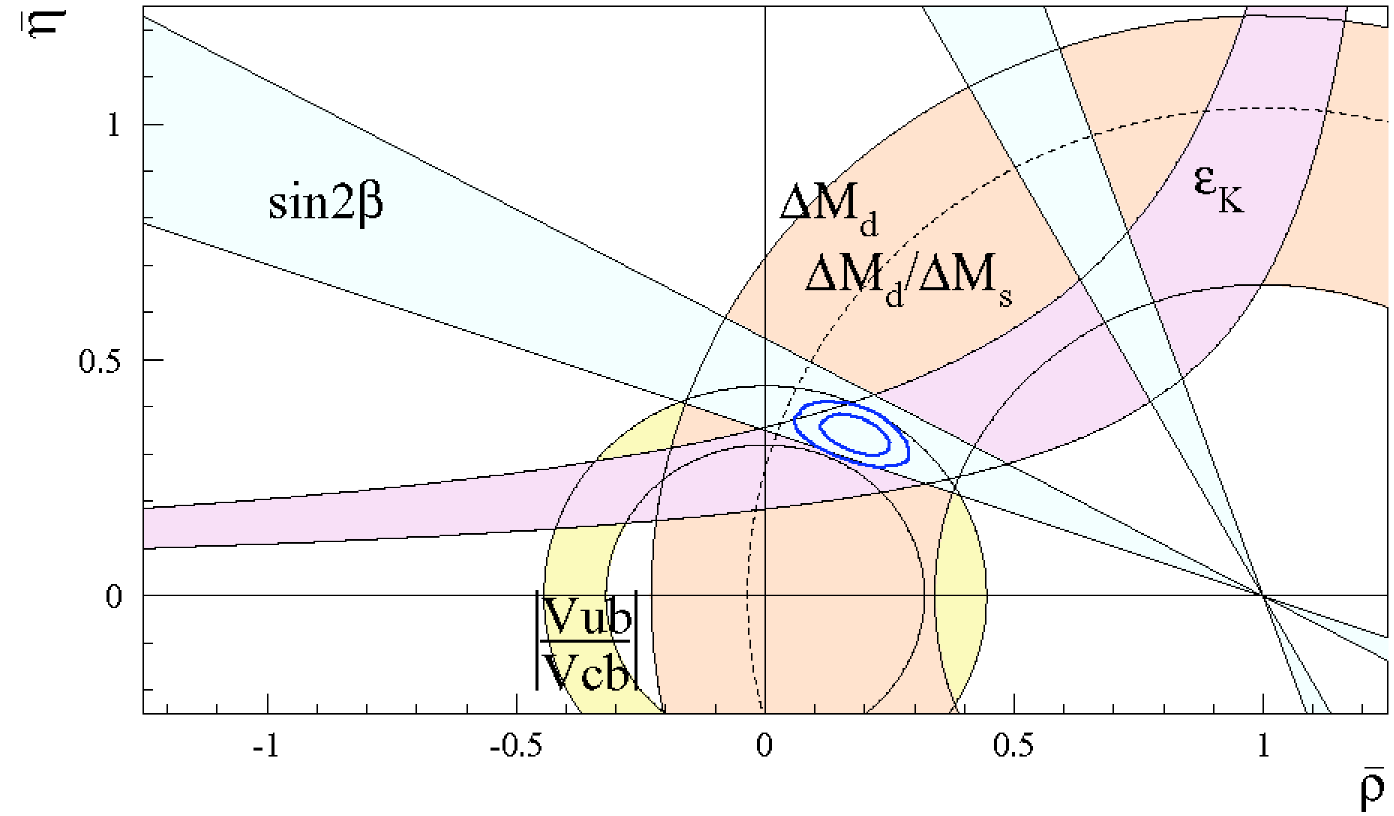
Lattice QCD calculations have become essential to some of the central goals of the HEP experimental program.



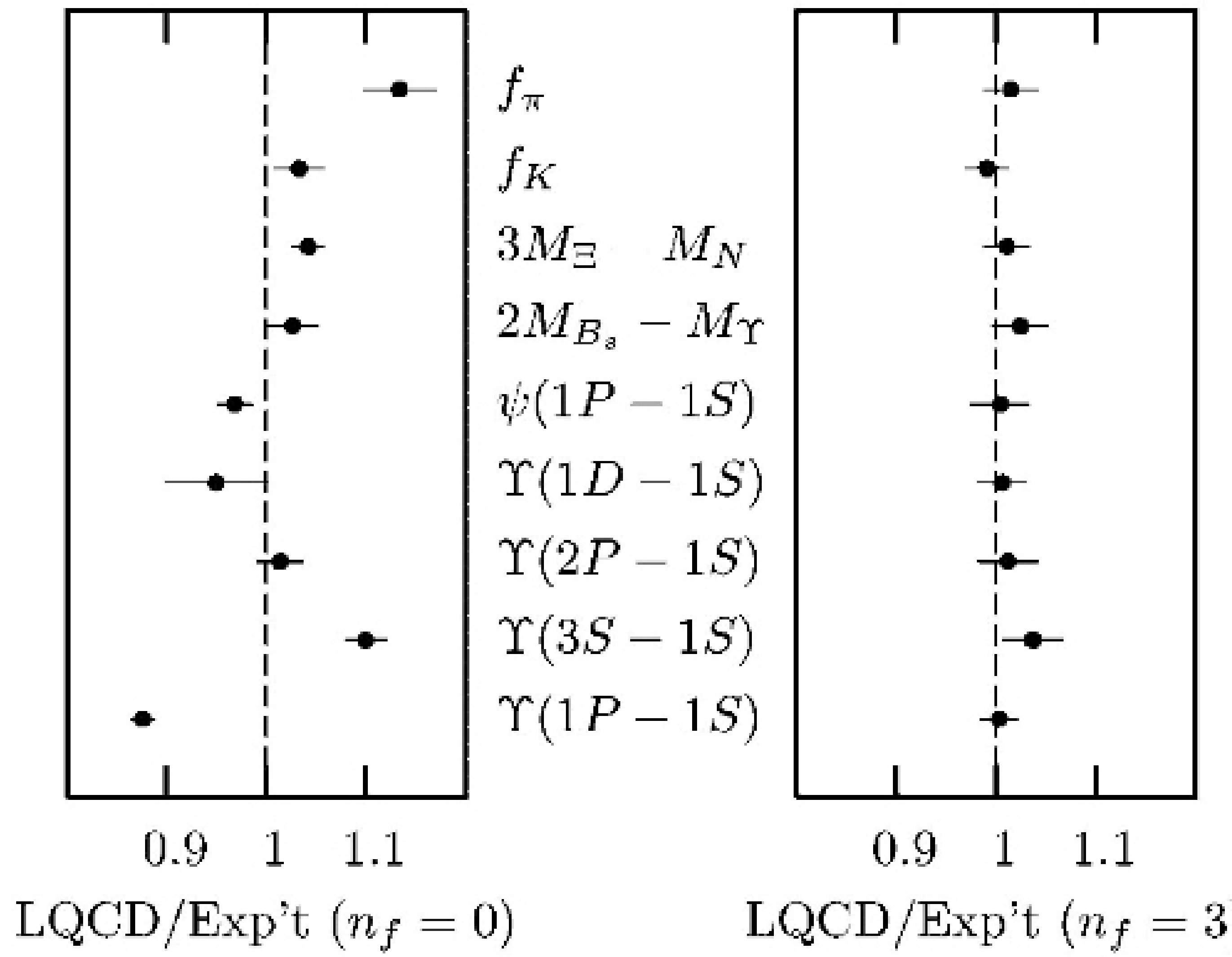
M. Ciuchini **hep-ph/0307195.**

E. g., potential to improve the ρ–η plane is huge.
Of the five best constraints:

K K bar mixing currently dominated by lattice uncertainties.
B B bar currently dominated by lattice uncertainties.
Bs Bs bar will be dominated by lattice uncertainties.
Vub: ($B\rightarrow\pi l\nu$) will be dominated by lattice uncertainties.
sin2β: dominated by experimental uncertainty.

Recent big progress with unquenched improved staggered fermions.

Several groups compared their <u>simplest</u> calculations. 10% disagreement quenched → few per cent agreement unquenched.



C.T.H. Davies *et al.*,
Phys.Rev.Lett.92:022001,2004, hep-lat/0304004.

What about slightly more complicated quantities?
Do other light quark methods agree?

The progress was written up in nice articles in Physics Today and Nature.

High-Precision Lattice QCD Confronts Experiment

C. T. H. Davies,[1] E. Follana,[1] A. Gray,[1] G. P. Lepage,[2] Q. Mason,[2] M. Nobes,[3] J. Shigemitsu,[4] H. D. Trottier,[3] and M. Wingate[4]
(HPQCD and UKQCD Collaborations)

arXiv:hep-lat/0304004 v1 7 Apr 2003

For almost thirty years precise numerical studies of nonperturbative QCD, formulated on a space-time lattice, have been stymied by our inability to include the effects of realistic quark vacuum polarization. In this paper we present detailed evidence of a breakthrough that may now permit a wide variety of nonperturbative QCD calculations including, for example, high-precision B and D meson decay constants, mixing amplitudes, and semi-leptonic form factors — all quantities of great importance in current experimental work on heavy-quark physics. The breakthrough comes from a new discretization for light quarks: Symanzik-improved staggered quarks [1, 2, 3, 4, 5, 6, 7, 8].

Quark vacuum polarization is by far the most expensive ingredient in a QCD simulation. It is particularly difficult to simulate with small quark masses, such as u and d masses. Consequently, most lattice QCD (LQCD) simulations in the past have either omitted quark vacuum polarization ("quenched QCD"), or they have included effects for only u and d quarks, with masses 10–20 times larger than the correct values. This results in uncon-

Lattice Quantum Chromodynamics Comes of Age

Quantum chromodynamics is the elegant but notoriously intractable theory of the strong interactions. Recent advances in numerical computer simulation are beginning to reveal, in impressive detail, what the theory predicts.

Carleton DeTar and Steven Gottlieb

Lattice QCD

High-precision calculations

Lattice window on strong force

Ian Shipsey

A long-awaited breakthrough has been made in lattice quantum chromodynamics — a means of calculating the effect of the strong force between sub-atomic particles that could, ultimately, unveil new physics.

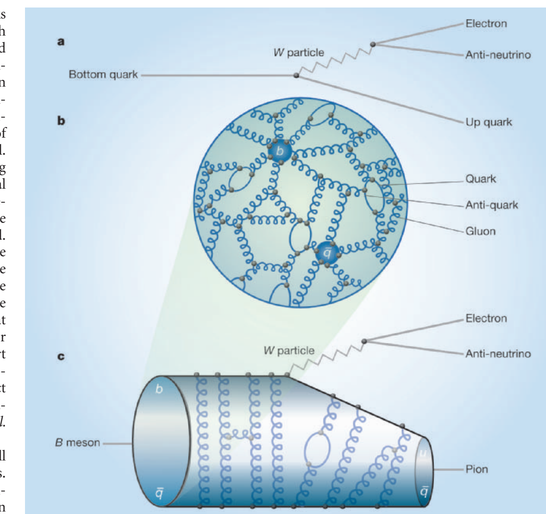


Figure 1 **Bottom's up.** a, **An idealized representation of the decay of a free bottom quark into an up quark. In the standard model of particle physics, the process occurs through the weak force, mediated by a *W* particle, and also produces an electron and an anti-neutrino.** b, **In the real world, however, there is no such thing as a free quark. Instead, a bottom quark exists in a bound state with other quarks — such as in a *B* meson, bound by the exchange of gluons to an anti-quark. Gluons and quark pairs are constantly emitted then reabsorbed; only a fraction of this 'sea' of particles is shown here.** c, **So the realistic picture of the decay of a bottom quark is complex. The *B* meson — a bottom quark and anti-quark pair — becomes a pion (an up quark and an anti-quark), but the route is obscured by the mass of gluons and quarks (of which, again, only a fraction are shown). Calculating the details of the process is fiendishly complicated. But new advances in lattice quantum chromodynamics mean that precise theoretical correction factors can be worked out, and the problem effectively reduced to the simple process shown in** a.

would be no matter in the Universe today. So how did that asymmetry arise?

If heavy particles that existed in the early Universe decayed preferentially into matter over antimatter, that could have created the matter excess. In the standard model, two types of quark, bottom and strange, do decay asymmetrically. But this effect alone is far too small to account for the asymmetry. However, there are many theories that predict the existence of other, massive particles that could readily produce the asymmetry. And because of the connection between asymmetry and mass, these theories also address other puzzles, such as why electrons are almost 10,000 times lighter than bottom quarks.

Searching for evidence of these particles can be done directly or indirectly: powerful accelerators, reaching ever higher energies, could create these mysterious particles; or there is the precision approach of looking for subtle deviations in the properties of known particles, influenced by the unknown. If

Paul Mackenzie

These are examples of some of the “golden quantities of lattice QCD: single stable meson processes. Other examples:

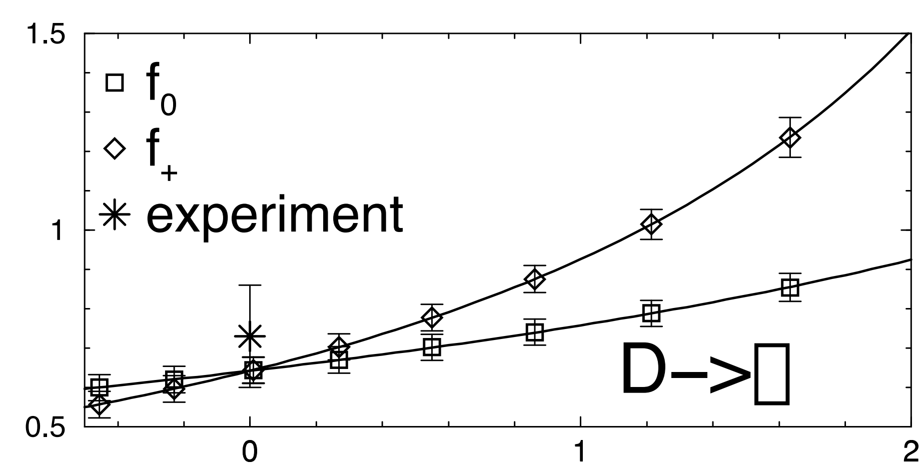
KK bar, BB bar, and BsBs bar mixing,
$B \to \pi l \nu$, $B \to D l \nu$,
$D \to \pi l \nu$, $D \to K l \nu$,
$K \to \pi l \nu$.

Example of current work : $D \to \pi l \nu$.

Cleo-c will measure f_D /$D \to \pi l \nu$ and f_{Ds}/$D \to K l \nu$ to 2%. Interesting and rare CKM independent test of lattice heavy-light methods.

One-loop perturbative calcutions (in progress) will leave 8-10% perturbative uncertainties. Goal: make all other uncertainty significantly smaller than this.

f_+^{DK}=0.75, f_+^{Dpi}=0.63. (Preliminary!)



M. Okamoto et al., at Lattice 2003, hep-lat/0309107.

Fermilab's lattice work is part of DoE's national effort to establish computational infrastructure for lattice QCD initiated under the SciDAC program.

US "Lattice QCD Executive Committee" (Sugar, chair, Brower, Christ, Creutz, Mackenzie, Negele, Rebbi, Sharpe, Watson) reports to DoE on plans and needs of US lattice QCD.

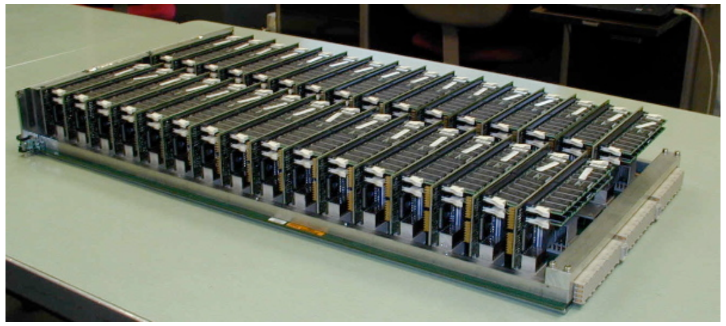
$2M/year, three-year SciDAC grant will probably be extended through '05.

Two major components of national program:

Large, tightly coupled clusters (Fermilab/JLab):

Nonlocal communication through switch, well understood user environment.

QCDOC (Columbia/BNL):



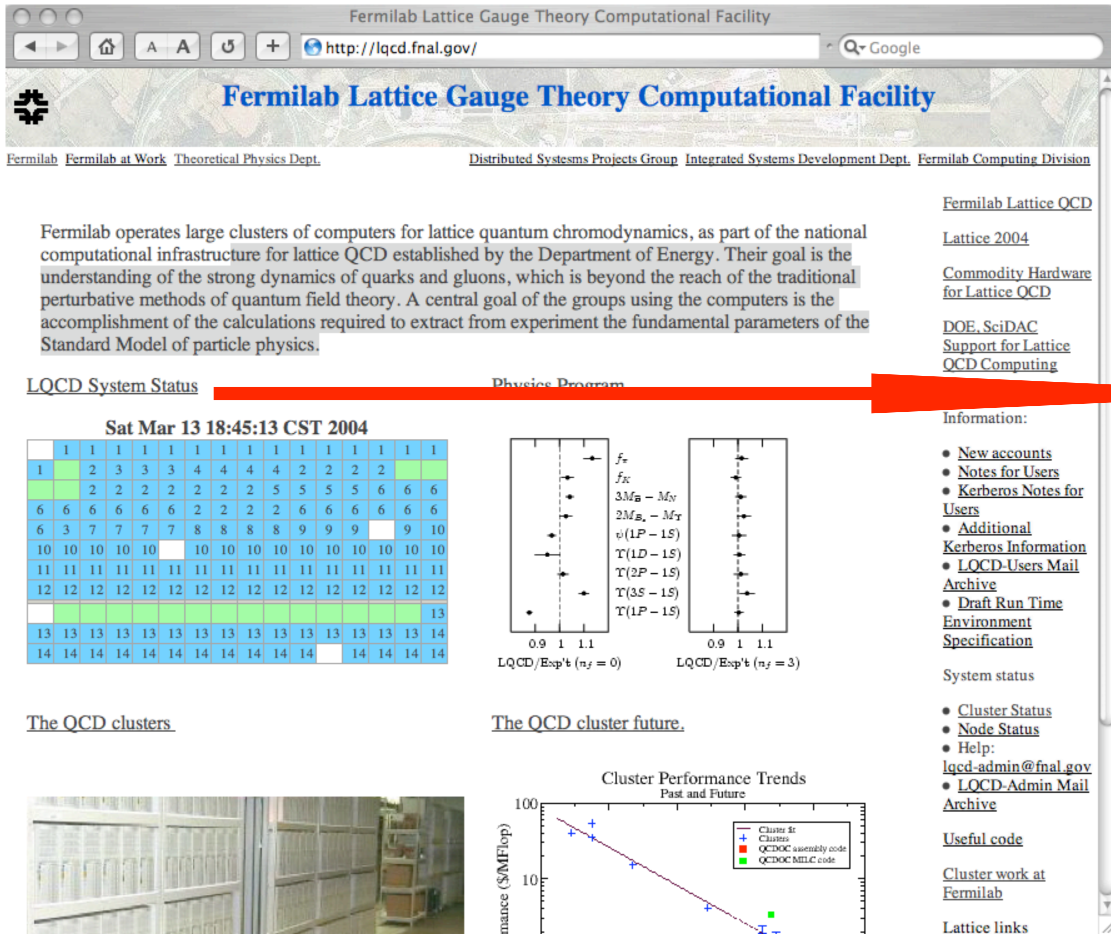
Local, highly scalable communication.

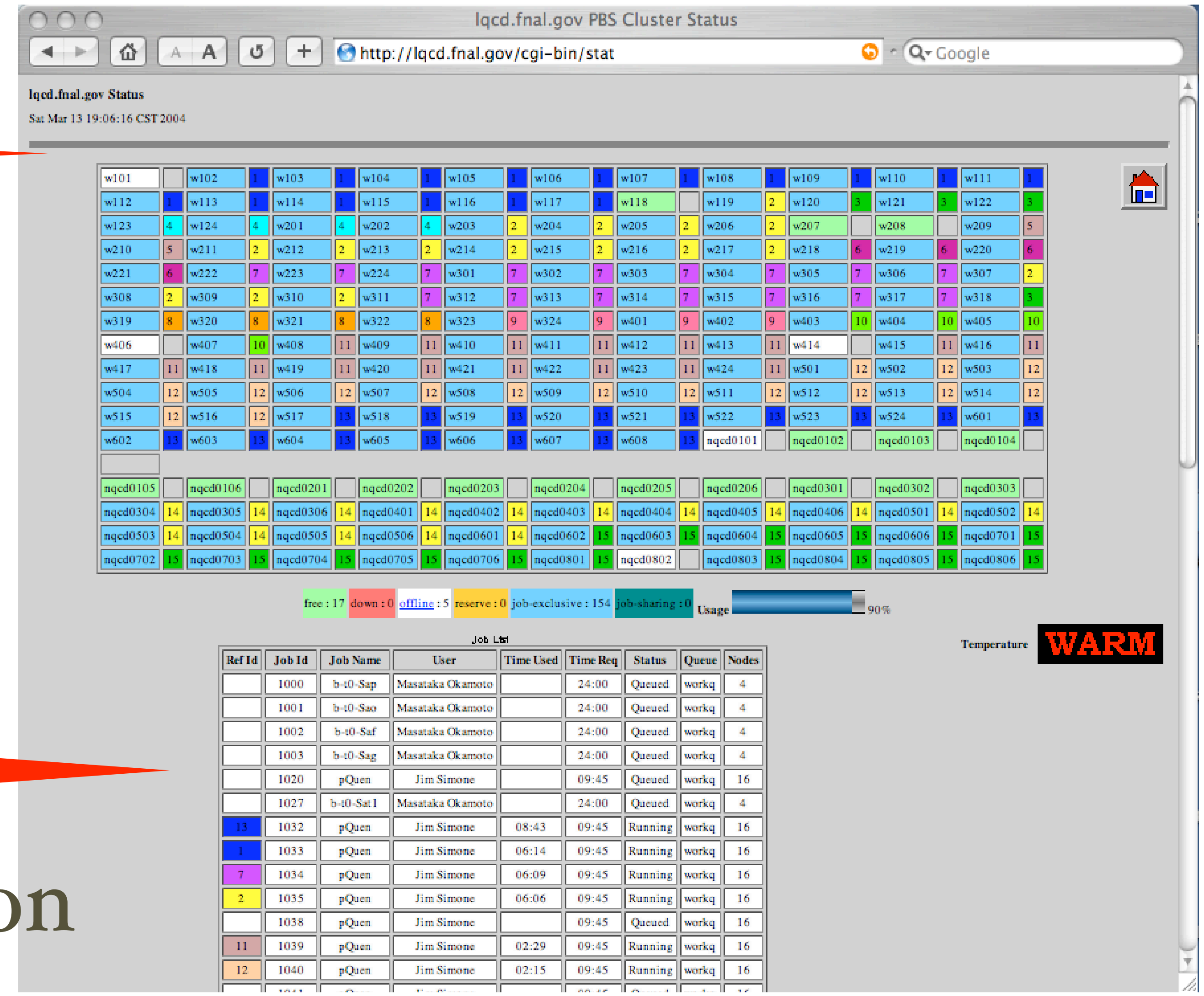
Fermilab lattice cluster effort is led by Don Holmgren.

The clusters are currently housed in the New Muon Lab.

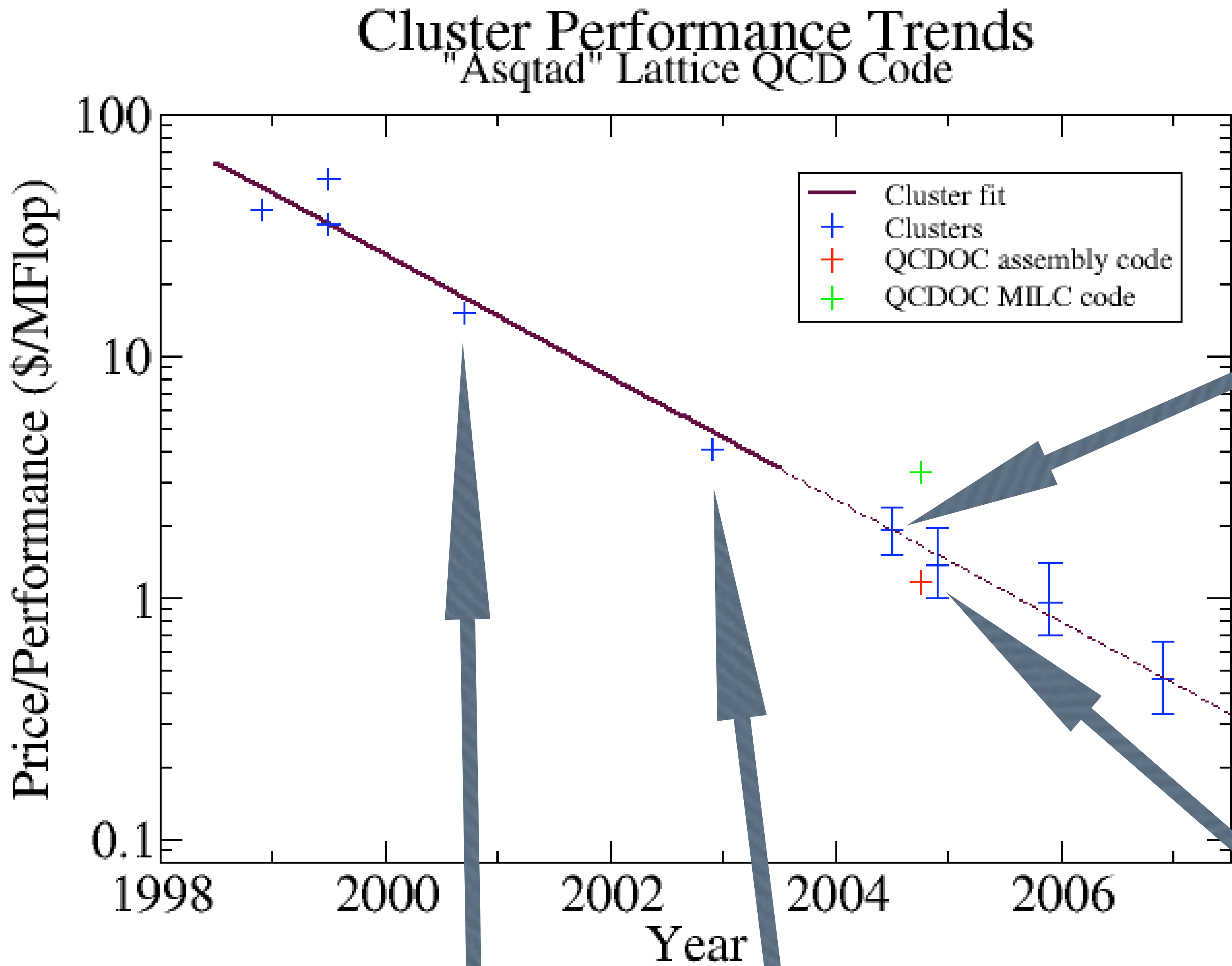
The 172 node Pentium 4 cluster.
~100 GFlops.

http://lqcd.fnal.gov





Job list a mixture of perturbation theory and valence calculation and analysis;
1 node, 4 node, 16 node jobs, etc.



2004:
128 P4 singles,
reuse Myrinet switch.
Incremental cost:
$1/MF.

256 node, P4 singles?
Infiniband switch.

2005: 512 node,
$1M, 1 TF.

2006: 1024 node,
$1.5 M, 3 TF
(or double).

At February, 2004 HEPAP meeting, Bob Sugar, in a well-received talk, reported the "absolute minimum support required for health of field".

Our answer: $3M/year:

	2004	2005	2006	...
QCDOC	$5M, 5 TF		$0	
HEP Clusters	$1 M, 1 TF		$3 M, 6TF?	

DoE-HEP response: $2M/year.

Discussions with Nuclear and ASCR are ensuing.